5.2. Description of the LINTUL-POTATO crop growth model

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5.2.1. Introduction

Crop growth under favourable conditions is observed to be often proportional to the amount of intercepted light. The **L**ight **IN**terception and **U**ti**L**isation model LINTUL1 is based upon this observation. The model simulates potential growth of a crop, i.e. its dry matter accumulation under ample supply of water and nutrients in a pest-, disease and weed free environment, under the prevailing weather conditions. The rate of dry matter accumulation is a function of irradiation and crop characteristics. Dry matter production is modelled as the product of light interception and a constant light use efficiency. The dry matter produced is partitioned among the various plant organs, using partitioning factors defined as a measured function of the phenological development stage of the crop. The dry weights of the plant organs are obtained by integration of their growth rates over time. LINTUL1 requires as input physiological properties of the crop and the actual weather conditions at the site, characterised by its geographical latitude, i.e. daily maximum and minimum temperatures and irradiation for each day of the year during the cropping season.

Crop growth under water limited conditions is simulated by the LINTUL2 model by including a water balance of crop and soil in the LINTUL1 model. Conditions are still optimal with respect to other growth factors, i.e. nutrients are ample available and the environment is pest-, disease- and weed-free. The effect of altered water relations is transmitted through two variables, one acting on total crop growth and the other one acting on root-shoot partitioning of dry matter. Additional environmental input data are vapour pressure, wind speed, precipitation and soil characteristics as soil water content at wilting point, field capacity, full saturation etc.. These characteristics can be estimated from soil physical properties which are documented in soil maps.

The objective of this section is to give a detailed description of the model for potential potato production and to show the possibility to apply this model in ecoregional research. LINTUL1 is written in FST, the FORTRAN Simulation Translator (van Kraalingen *et al.*, 1994), which runs on various computer platforms, e.g. VAX-mainframe, IBM-PC or compatible, and Apple-Macintosh.

The explanatory text follows as closely as possible the computer listing of the model. Each section starts with a number of lines copied from this listing. In the following text, the inevitably awkward abbreviative terminology so typical for computer modelling, is then explained. Units of all variables and data are specified.

```
DEFINE_CALL GLA(INPUT,INPUT,INPUT,INPUT,INPUT,INPUT,INPUT,INPUT, ...
                INPUT,INPUT,OUTPUT)
TITLE LINTUL1
```

FST requires, before the program starts, a definition of the calls for subroutines that are used in the program. All variables in the subroutine-call have to be defined as INPUT or

OUTPUT variables. These definitions will be used by FST for sorting the program lines. After the definition of the subroutine-call the program starts with the TITLE of the program.

5.2.2. Initial conditions and run control

```
*  Initial conditions
INCON ZERO = 0.
*  Initial leaf area index (LAII: m2/m2)
   LAII = NPL * LA0
```

FST requires the name of a constant as initial value for an integration. In case this integration starts at zero (e.g. summation of temperature) the initial constant ZERO is used.

The initial leaf area index crop emergence (LAII, m^2_{leaf} m^{-2}_{ground}) is calculated as the product of initial Leaf Area per plant (LA0, m^2_{leaf} $plant^{-1}$) and the Number of PLants per surface area (NPL, #plants.m^{-2}_{ground}).

* Run control

```
TIMER STTIME = 1.; FINTIM = 200.; DELT = 1.; PRDEL = 5.
TRANSLATION_GENERAL DRIVER='EUDRIV'
PRINT LAI, WSOTHA, WSO, WST, WLV, WRT, TSUM, DAVTMP, DTR
```

Simulation may start earlier than emergence. This is specified in the TIMER statement (STTIME = 1 means: 1 January). Simulation is executed with time steps of one day (DELT=1.), with rectilinear integration (Euler) of the rates (DRIVER='EUDRIV'). Output is produced every fifth day (PRDEL=5.). To make sure that the simulation does not continue endlessly, the finish time (FINTIM) is set at day 200. The simulation will also stop when the FIN statement is greater than 0.

In the PRINT line any variable can be specified. Values are written to the output file at every print interval (PRDEL).

```
FINISH FIN > 0.
DYNAMIC
FIN  = INTGRL(ZERO,RFIN)
RFIN = REAAND(TSUM-100.,0.01-LAI)
```

The simulation stops also if the crop is mature. This occurs if the Leaf Area Index (LAI) is smaller than 0.01 $m^2.m^{-2}$. In order to prevent that the simulation stops when the leaves have just emerged, the temperature sum (TSUM) has to be greater than 100 °Cd (TSUM>100). This means that simulation stops at the end of the growing season when the leaves have become detoriated (LAI<0.01).). For explanation of the INTGRL and REAAND functions, see the description of FST (van Kraalingen *et al.*, 1994)

5.2.3. Environmental data and temperature sum

```
WEATHER WTRDIR='C:\SYS\WEATHER\'; CNTR='PER'; ISTN=3; IYEAR=1985
*      Reading weather data from weather file:
*      RDD     Daily global radiation          J/(m2*d)
*      TMMN    Daily minimum temperature       degree C
*      TMMX    Daily maximum temperature       degree C
       DTR     = RDD/1.E+6
       DAVTMP  = 0.5 * (TMMN + TMMX)
       DTEFF   = MAX ( 0., DAVTMP-TBASE )
       EMERG   = MAX( INSW(TIME-DOYEM, 0., 1.), INSW(-LAI,1.,0.) )
       TSUM    = INTGRL(ZERO, RTSUM)
       RTSUM   = DTEFF*EMERG
```

Actual daily total global radiation (RDD, J m^{-2} d^{-1}) is read from the weather data file, which contains measured values for solar radiation (400 - 2000 nm) for all days of the year. RDD is converted into other units by division by 10^6, to give DTR in MJ m^{-2} d^{-1}.

Daily maximum and minimum temperatures (TMMX and TMMN, respectively, °C) are also read from the weather data file, containing measured values for all days of the year. DAVTMP is the daily average temperature. Since many growth processes are temperature dependent above a certain threshold temperature, an effective temperature (DTEFF) is calculated. For potato, the threshold value (TBASE) is 2 °C. The variable EMERG equals 0 before emergence, and 1 after emergence, when DOY is equal or larger than the daynumber of emergence (DOYEM) is or when there are leaves, LAI>0. For explanation of the MAX and INSW functions, see the description of FST (van Kraalingen *et al.*, 1994). Note that TIME may become larger than 365, in case the simulation runs from one calendar year into the next year.

Phenological development of crops is more closely related to thermal time, i.e. the accumulated number of degree-days after emergence, than to the age of the crop in days. Therefore, the model calculates the temperature sum (TSUM, °Cd) by accumulating the daily values of effective temperature after emergence (RTSUM, °C).

5.2.4. Leaf growth and senescence

```
  ***    3. Leaf growth and senescence
         CALL GLA(
TIME,DOYEM,DTEFF,TSUM,LAII,RGRL,DELT,SLA,LAI,GLV,GLAI)
  *      dry matter leaf growth rate
         GLV    = FLV * GTOTAL
  *      death rate of leaf area index
         DLAI    = MIN(DRDV+DRSH, LAI/DELT + GLAI)
  *      death rate leaves due to ageing
         DRDV    = INSW(TSUM-725., 0., DRDV0 * DTEFF)
  *      death leaves due to self-shading
         DRSH    = LIMIT(0., DRSH0, DRSH0 * (LAI-LAICR) / LAICR)
  *      death rate of leaves
         DLV    = WLVG * DLAI/NOTNUL(LAI)
  *      growth rate of LAI
         RLAI   = GLAI - DLAI
         LAI    = INTGRL(ZERO, RLAI)
```

The area of green leaves is the major determinant for light interception and utilisation. The leaf area index (LAI, m^2 (leaf) m^{-2} (ground)) is obtained by integrating the net result (RLAI, $m^2\ m^{-2}\ d^{-1}$) of the leaf growth rate (GLAI, $m^2\ m^{-2}\ d^{-1}$), and the leaf senescence rate (DLAI, $m^2\ m^{-2}\ d^{-1}$).

GLAI is calculated, depending on the phenological development stage, in the Subroutine GLA. Before seedling emergence (TIME < DOYEM), GLAI equals zero. At emergence, GLAI = LAII/DELT. After emergence, light intensity and temperature are the environmental factors influencing the rate of leaf area expansion.

During juvenile growth, temperature is the overriding factor, as the rate of leaf appearance and final leaf size are constrained by temperature through its effect on cell division and extension, rather than by the supply of assimilates. In these early stages, leaf area increases approximately exponentially over time. Examination of unpublished field data suggests that a safe approximation is to restrict the exponential phase to the situation where LAI < 0.75 $m^2\ m^{-2}$ and TSUM < 330 °Cd. This is programmed in the Subroutine GLA, which is reproduced at the last page of this program description. Exponential leaf area development is described analytically by:

```
LAI(t+DELT) = LAI(t) * EXP(RGRL * DTEFF * DELT)
```

so that the rate of increase in leaf area during juvenile growth is:

```
GLAI = (LAI(t + DELT) - LAI(t)) / DELT
     = LAI(t) * (EXP(RGRL * DTEFF * DELT) - 1.) / DELT
```

in which LAI(t) is the current leaf area ($m^2\ m^{-2}$), RGRL is the relative growth rate of leaf area, expressed per degree-day ($(°Cd)^{-1}$), DELT is the time step of integration (d) and DTEFF is the daily effective temperature (°C).

In later development stages, leaf area expansion is increasingly restricted by assimilate supply. Branching and tillering generate an increasing number of sites per plant where leaf initiation can take place and mutual shading of plants further reduces the assimilate supply per growing point. During this stage (LAI > 0.75 or TSUM > 330 °Cd), the model calculates the growth of leaf area by multiplying the simulated increase in leaf weight (GLV, g $m^{-2}\ d^{-1}$) by the specific leaf area of new leaves (SLA, $m^2\ g^{-1}$).

The senescence rate of LAI (DLAI, d^{-1}) is set at the minimum of either a relative death rate due to ageing (DRDV) and self-shading, DRSH, or either due to developmental ageing. The relative death rate due to shading equals zero for LAI smaller than 4 (= LAICR), and above that value increases linearly with increasing LAI till a maximum value of 0.03 (= DRSHO) at LAI = 8. For the meaning of the LIMIT function, see the description of FST, van Kraalingen *et al.*, 1994.

DRDV equals zero as long as TSUM < 725 and is a function of the average daily temperature (DAVTMP, °C) for TSUM > 725.

The death rate of leaves in terms of weight (DLV, g $m^{-2}\ d^{-1}$) is defined using the same relative senescence rate (DLAI) that also applies to LAI, but now multiplied with the weight of the green leaves (WLVG, g m^{-2}).

5.2.5 *Light interception and total crop growth rate*

```
PARINT = 0.5 * DTR    * (1. - EXP(-KDF*LAI))
GTOTAL = LUE * PARINT
```

Photosynthetically active radiation (PAR), wavelengths between 400 and 700 nm, is about 50% of the incoming global radiation (0.5*DTR). The daily values of intercepted Photosynthetically active radiation (PARINT, MJ $m^{-2}\ d^{-1}$) are derived by assuming that light interception increases with LAI according to a negative exponential function of leaf area index, characterised by a crop-specific light extinction coefficient (KDF, $m^2_{ground}\ m^{-2}_{leaf}$).

The overall daily growth rate of the crop (GTOTAL, g $m^{-2}\ d^{-1}$) is then calculated by multiplying the amount of light intercepted by a constant light use efficiency (LUE, g MJ^{-1}).

5.2.6. Growth rates and dry matter production of plant organs

```
FRT    = AFGEN( FRTTB, TSUM )
FLV    = AFGEN( FLVTB, TSUM )
FST    = AFGEN( FSTTB, TSUM )
FSO    = AFGEN( FSOTB, TSUM )
* state variable integration
WLVG   = INTGRL( ZERO, RWLVG)
WLVD   = INTGRL( ZERO, DLV  )
WST    = INTGRL( ZERO, RWST )
WSO    = INTGRL( ZERO, RWSO )
WRT    = INTGRL( ZERO, RWRT )
WLV    = WLVG + WLVD
* rate calculation
RWLVG  = GTOTAL * FLV - DLV
RWST   = GTOTAL * FST
RWSO   = GTOTAL * FSO
RWRT   = GTOTAL * FRT
* conversion from WSO,g/m2 to WSOTHA tons/ha
WSOTHA = WSO / 100.
```

Partitioning of biomass over the various plant organs is described by fixed distribution factors, defined as functions of the temperature sum. Before tuber initiation (TSUM < 142) the highest distribution factors are those for roots (FRT), leaves (FLV) and stems (FST), thereafter most of the biomass is allocated to the storage organs, i.e. tubers (FSO). This allocation-pattern is embodied in the FUNCTION-statements given in the next section.

Dry weights of the various plant organs (roots (WRT, g m^{-2}), green leaves (WLVG, g m^{-2}), dead leaves (WLVD, g m^{-2}), stems (WST, g m^{-2}), storage organs (WSO, g m^{-2})) are obtained through integration of the respective growth rates. For convenience, the program calculates yield in tons/ha as well (WSOTHA, t ha^{-1}).

5.2.7. Functions and parameters for potato

```
*     Section 1
* number plants and initial leaf area
* NPL: plants/m2 soil ; LA0: m2 leaf/plant
PARAM NPL = 3.8; LA0 = 0.0155

*     Section 2
* base temperature,
* TBASE: oC
PARAM TBASE = 2.
```

```
*     Section 3
* day number of crop emergence and relative LAI growth rate
* DOYEM: day ; RGRL: 1/Cd
PARAM DOYEM = 132.  ; RGRL  = 0.012
* specific leaf area and critical leaf area for death due to
* selfshading
* SLA: m2/g dm; LAICR: m2 leaf/m2 soil
PARAM SLA   = 0.03 ; LAICR = 4.

* initial death rates of leaves due to ageing and shading
* DRDV0: 1/d, DRSH0: 1/d
PARAM DRDV0 = 0.004; DRSH0 = 0.05

*     Section 4
* light use efficiency and extinction coefficient
* LUE: g/MJ(PAR); KDF: m2soil/m2 leaf
PARAM LUE = 2.7; KDF = 1.0

*     Section 5
*     Partitioning tables for leaves (LV), stems (ST),
*     storage organs (SO) and roots (RT):
FUNCTION FLVTB  = 0.,0.6, 142.,0.6, 465.,0.0 , 572.,0.0, 2500.,0.0
FUNCTION FSTTB  = 0.,0.2, 142.,0.2, 465.,0.2 , 572.,0.0, 2500.,0.0
FUNCTION FSOTB  = 0.,0.0, 142.,0.0, 465.,0.75, 572.,1.0, 2500.,1.0
FUNCTION FRTTB  = 0.,0.2, 142.,0.2, 465.,0.05, 572.,0.0, 2500.,0.0

END

* Start of rerun section

PARAM DOYEM = 60.
END

STOP
* Start of Subroutine section (see Section 3)
* -----------------------------------------------------------------
*
*SUBROUTINE                                                      GLA
*
*Purpose:This subroutine computes daily increase of leaf area index
*
*                          (m2     leaf/     m2     ground/     d)
*
* -----------------------------------------------------------------
*
      SUBROUTINE
GLA(TIME,DOYEM,DTEFF,TSUM,LAII,RGRL,DELT,SLA,LAI,GLV,
     $               GLAI)
      IMPLICIT REAL (A-Z)
```

```
*---- Growth during maturation stage:
      GLAI = SLA * GLV

*---- Growth during juvenile stage:
      IF ((TSUM.LT.330.).AND.(LAI.LT.0.75))
     $   GLAI = LAI * (EXP(RGRL * DTEFF * DELT) - 1.) / DELT

*---- Growth at day of seedling emergence:
      IF ((TIME.GE.DOYEM).AND.(LAI.EQ.0.))
     $   GLAI = LAII / DELT

*---- Growth before seedling emergence:
      IF (TIME.LT.DOYEM) GLAI = 0.

      RETURN
      END
```

5.2.8. Definitions of the abbreviations used in de models LINTUL1

Name	Description	Units*
CNTR	Country code for weather file	-
DAVTMP	Daily average temperature	°C
DELT	Time step of integration	d
DLAI	Death rate of leaf area index	$m^2\ m^{-2}\ d^{-1}$
DLV	Death rate of leaves	$g\ m^{-2}\ d^{-1}$
DOY	Daynumber of year	d^{-1}
DOYEM	Daynumber at crop emergence	d^{-1}
DRDV	Relative death rate of leaves due to ageing	d^{-1}
DRDV0	Initial relative death rate of leaves due to ageing	d^{-1}
DRSH	Relative death rate of leaves due to shading	d^{-1}
DRSH0	Maximum relative death rate of leaves due to shading	d^{-1}
DTEFF	Daily effective temperature	°C
DTR	Daily global radiation	$MJ\ m^{-2}\ d^{-1}$
DTRJM2	Daily global radiation	$J\ m^{-2}\ d^{-1}$
EMERG	Auxiliary variable indicating crop emergence	-
FINTIM	Finish time of simulation run	d
FLV	Fraction of dry matter allocated to the leaves	-
FLVTB	Table of FLV as a function of TSUM	-
FRT	Fraction of dry matter allocated to the roots	-
FRTMOD	Relative modification of FRT by drought	-
FRTTB	Table of FRT as a function of TSUM	-
FSO	Fraction of dry matter allocated to the storage organs	-
FSOTB	Table of FSO as a function of TSUM	-
FST	Fraction of dry matter allocated to the stems	-
FSTTB	Table of FST as a function of TSUM	-
GLA	FORTRAN subroutine to calculate GLAI	-
GLAI	Growth rate of leaf area index	$m^2\ m^{-2}\ d^{-1}$
GLV	Growth rate of leaf dry matter	$g\ m^{-2}\ d^{-1}$
GTOTAL	Growth rate of total crop dry matter	$g\ m^{-2}\ d^{-1}$
ISTN	Weather station number	-
IYEAR	Year	-
KDF	Extinction coefficient for Photosynthetically active radiation	$m^2\ m^{-2}$
LAI	Leaf area index	$m^2\ m^{-2}$
LAICR	Critical LAI beyond which leaves die due to self-shading	$m^2\ m^{-2}$

LAII	Initial leaf area index (at crop emergence)	$m^2\ m^{-2}$
LA0	Initial leaf area per plant (at crop planting)	m^2 $plant^{-1}$
LUE	Light use efficiency (dry matter produced per unit of intercepted Photosynthetically active radiation)	$g\ MJ^{-1}$
PARINT	Intercepted Photosynthetically active radiation	$MJ\ m^{-2}\ d^{-1}$
PRDEL	Time interval for printing	D
RAIN	Water input through rainfall	$mm\ d^{-1}$
RDD	Daily global radiation (weather file)	$J\ m^{-2}\ d^{-1}$
RGRL	Relative growth rate of LAI during exponential growth	$(°C\ d)^{-1}$
RLAI	Growth rate of LAI	$m^2\ m^{-2}\ d^{-1}$
RTSUM	Rate of increase of the temperature sum	°C
RWLVG	Net rate of increase weight of green leaves	$g\ m^{-2}\ d^{-1}$
RWRT	Rate of increase weight of roots	$g\ m^{-2}\ d^{-1}$
RWSO	Rate of increase weight of storage organs	$g\ m^{-2}\ d^{-1}$
RWST	Rate of increase weight of stems	$g\ m^{-2}\ d^{-1}$
SLA	Specific leaf area	$m^2\ g^{-1}$
STTIME	Start time of the simulation run	d
SVP	Saturation vapour pressure	kPa
TBASE	Base temperature	°C
TIME	Time from 1 January	d
TMMN	Daily minimum temperature (weather file)	°C
TMMX	Daily maximum temperature (weather file)	°C
TSUM	Temperature sum	°C d
WLV	Dry weight of leaves	$g\ m^{-2}$
WLVD	Dry weight of dead leaves	$g\ m^{-2}$
WLVG	Dry weight of green leaves	$g\ m^{-2}$
WLVI	Initial dry weight of green leaves (at crop emergence)	$g\ m^{-2}$
WRT	Dry weight of roots	$g\ m^{-2}$
WSO	Dry weight of storage organs	$g\ m^{-2}$
WSOTHA	Dry weight of storage organs	$t\ ha^{-1}$
WST	Dry weight of stems	$g\ m^{-2}$
WTRDIR	Weather directory	-
ZERO	Initial value used in integral statements	*Same unit as state variable*